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Nanotechnology and Its Impact on Construction

RT 251

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Building On
25 Years

Construction Industry Institute (CII)

Owner

- Abbott
- The AES Corporation
- Air Products and Chemicals, Inc.
- Alcoa
- Ameren Corporation
- American Transmission Company LLC
- Amgen Inc.
- Anheuser-Busch InBev
- Aramco Services Company
- Archer Daniels Midland Company
- BP America, Inc.
- Bristol-Myers Squibb Company
- Cargill, Inc.
- Chevron
- CITGO Petroleum Corporation
- Codelco-Chile
- ConocoPhillips
- DFW International Airport
- The Dow Chemical Company
- DuPont
- Eastman Chemical Company
- Eli Lilly and Company
- ExxonMobil Corporation
- General Motors Corporation
- GlaxoSmithKline
- Hovensa, LLC
- Intel Corporation
- International Paper
- Kaiser Permanente
- Marathon Oil Corporation
- National Aeronautics & Space Administration
- Naval Facilities Engineering Command
- NOVA Chemicals Corporation
- Occidental Petroleum Corporation
- Ontario Power Generation
- Petroleo Brasileiro S/A - Petrobras
- Praxair, Inc.
- The Procter & Gamble Company
- Progress Energy, Inc.
- Rohm and Haas Company
- Sasol Technology
- Shell Oil Company
- Smithsonian Institution
- Solutia Inc.
- Southern Company
- Sunoco, Inc.
- Tennessee Valley Authority
- Tyson Foods, Inc.
- U.S. Architect of the Capitol
- U.S. Army Corps of Engineers
- U.S. Department of Commerce/NIST/BFRL
- U.S. Department of Energy
- U.S. Department of Health & Human Services
- U.S. Department of State
- U.S. General Services Administration
- U.S. Steel
- Vale

Contractor

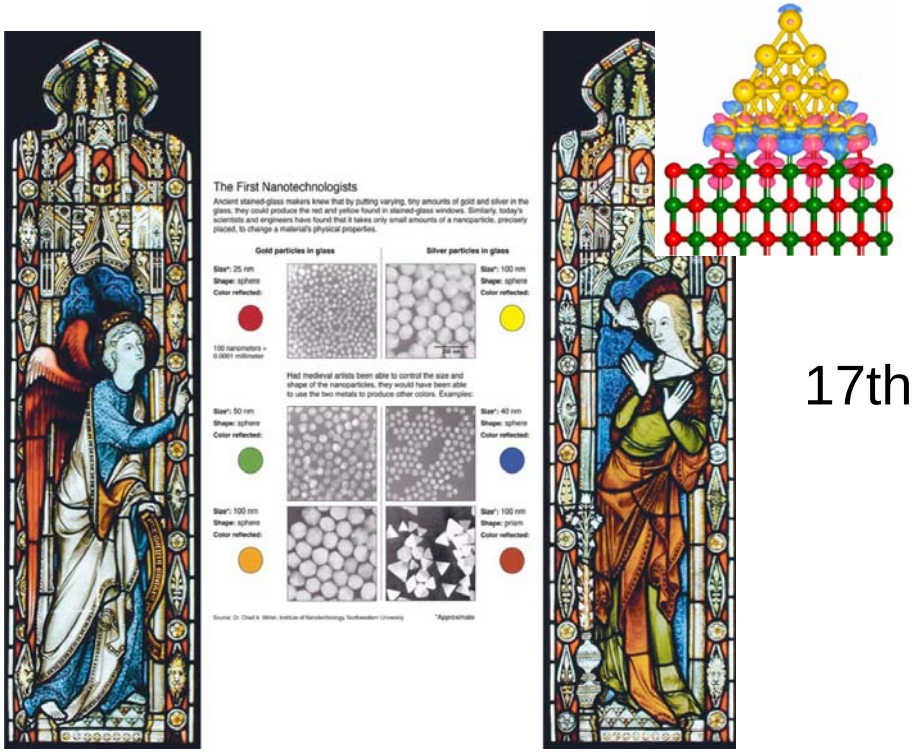
- Adolfson & Peterson Construction
- Aker Solutions
- Alstom Power Inc.
- AMEC, Inc.
- Atkins Faithful & Gould
- Autodesk, Inc.
- AZCO INC.
- Baker Concrete Construction Inc.
- Barton Malow Company
- Bateman Engineering N.V.
- Bechtel Group, Inc.
- BIS Frucon Industrial Services Inc.
- Black & Veatch
- Bowen Engineering Corporation
- Burns & McDonnell
- CB&I
- CCC Group, Inc.
- CDI Engineering Solutions
- CH2M HILL
- CSA Group
- Day & Zimmermann International, Inc.
- dck worldwide, LLC
- Dresser-Rand Company
- Emerson Process Management
- Fluor Corporation
- Foster Wheeler USA Corporation
- Grinaker-LTA/E+PC
- Gross Mechanical Contractors, Inc.
- GS Engineering & Construction Corporation
- Hargrove and Associates, Inc.
- Hatch
- Hill International, Inc.
- Hilti Corporation
- Jacobs
- JMJ Associates Inc.
- KBR
- Kiewit Power Construction
- Lauren Engineers & Constructors, Inc.
- M. A. Mortenson Company
- McDermott International, Inc.
- Mustang
- Parsons
- Pathfinder LLC
- Pegasus Global Holdings
- Primavera Systems, Inc.
- R. J. Mycka, Inc.
- S&B Engineers and Constructors, Ltd.
- The Shaw Group Inc.
- Siemens Energy, Inc.
- SNC-Lavalin Inc.
- Technip
- URS Corporation
- Victaulic Company
- Walbridge
- The Weitz Company, Inc.
- Worldwater & Solar Technologies
- WorleyParsons
- Zachry
- Zurich

Agenda

- Introduction to Nanotechnology
- Background Review
- Examples to Products and Application Areas
- Drivers in Construction, Benefits, Barriers, and Path Forward
- Risk Management
- Survey Results and Top Product Areas for Construction
- Question & Answering

Nanotechnology is not new …

Nanotechnology has been applied in ancient manufacturing by adding gold/silver or during careful manufacturing using carbon nanotubes



Source: Elder et al, 2008

17th Century

Source: Young 2006

Nanotechnology in future everyday life

Corrosion

Nano-particle paint to prevent corrosion

Cooling

Thermo-chromic glass to regulate the influx of light

Functional Surfaces

Organic Light Emitting Diodes (OLEDs) for displays

Photovoltaic film that converts light into electricity

LEDs are now powerful enough to compete with light bulbs

Scratchproof, coated windowpanes using the lotus effect

Maintenance

Menu card made of electronic cardboard

Nanotubes for new notebook displays

Fabrics coated to resist stains

Piezo mats prevent annoying vibrations

Hip joints made from biocompatible materials

The helmet maintains contact with the wearer

Intelligent clothing measures pulse and respiration

The Bucky-tube frame is as light as a feather, yet strong

Structures

Energy

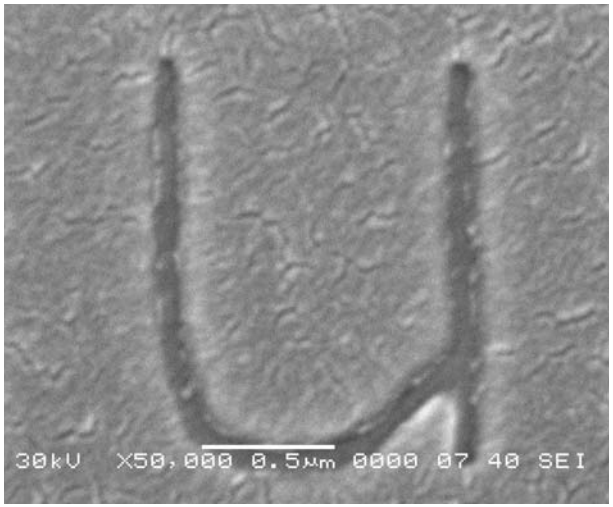
Fuel cells provide power for mobile phones and vehicles

Magnetic layers for compact data memory

Economic Growth → Social Progress → Minimizing Ecological Footprint

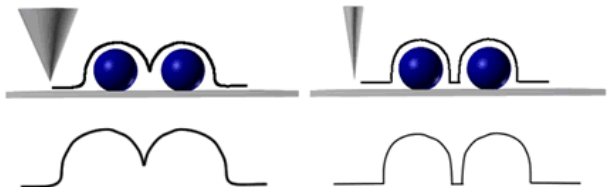
What is Nanotechnology?

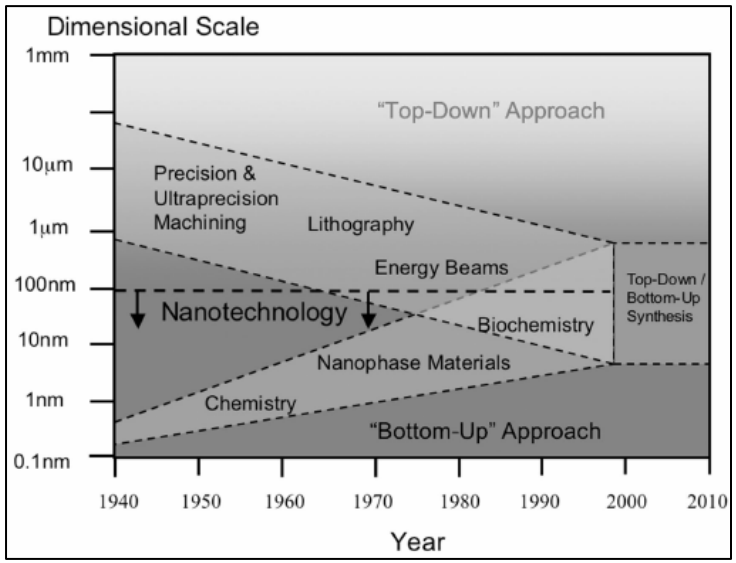
Construction Industry Institute®



- Nano is a Greek word and means “Dwarf ”
- Research and technology development
- Understand, create, use, and control matter
- Dimensions of <100 nanometer, “nanoscale”
- Fundamentally new properties and functions because of their nanoscale structure
- Ability to
  - image, measure, model, and manipulate matter on the nanoscale to exploit those properties and functions
  - integrate into systems spanning from nano- to micro- to macroscopic scales
- Examples: Structures, devices, and systems

Literature Review (1)

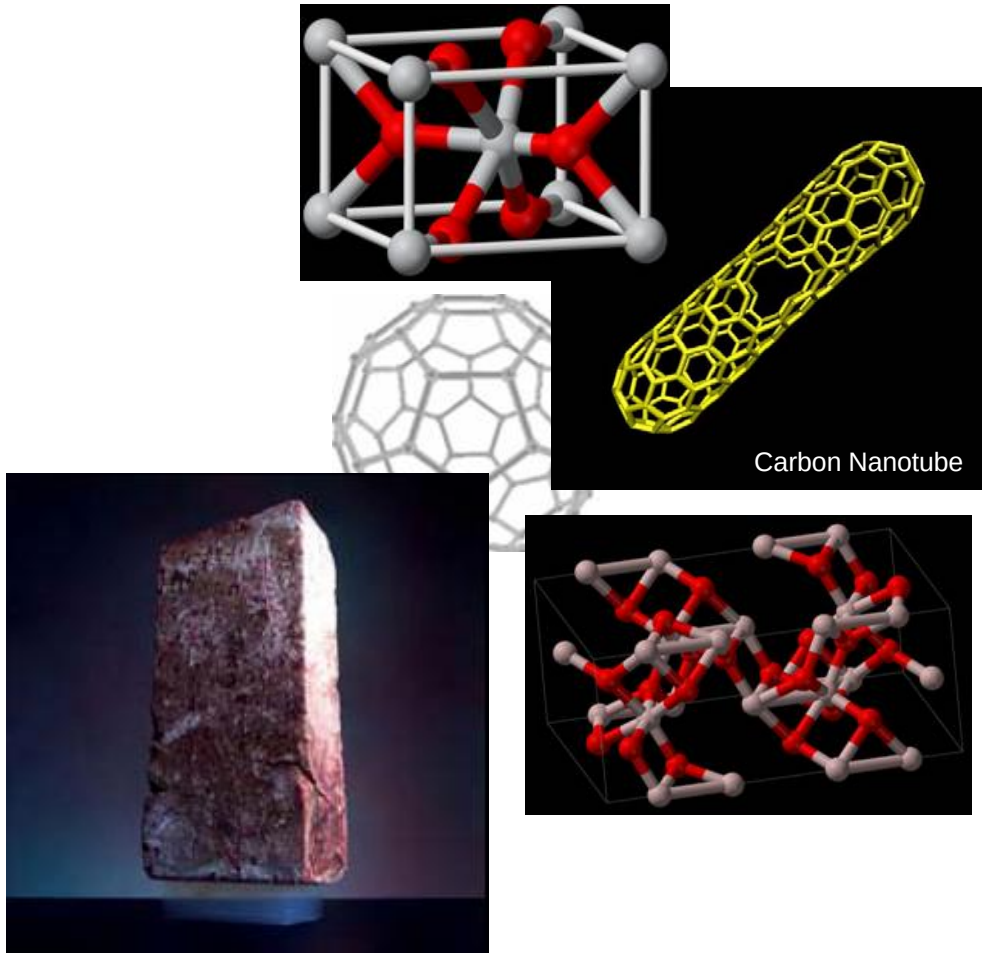




- **Nanofabrication Techniques and Tools**
  - "Top Down"
    - Created by processing of bulk materials
    - Current technology
    - Exploiting properties of nanoscale structures (e.g., nanoparticles)
  - "Bottom Up"
    - Designing and manipulating individual molecules from "bottom up"
    - Future technology, a.k.a. molecular manufacturing

Literature Review (2)

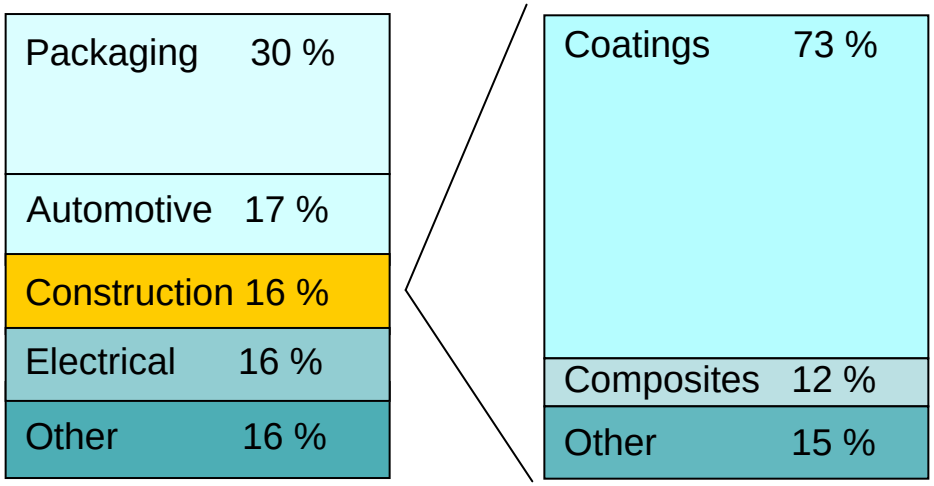
- **Materials and Properties**
  - TiO_2
  - Fullerenes
  - Carbon Nanotubes
  - Silica
  - Alumina
  - Magnesium and Calcium Nano-particles
  - Clays
  - Aerogels



Literature Review (2)

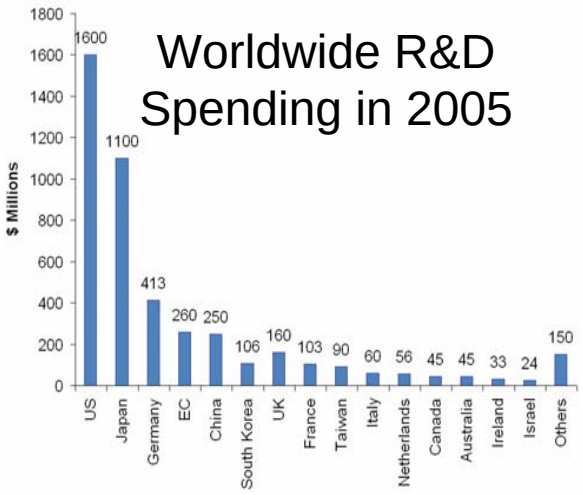
Transparent Concrete

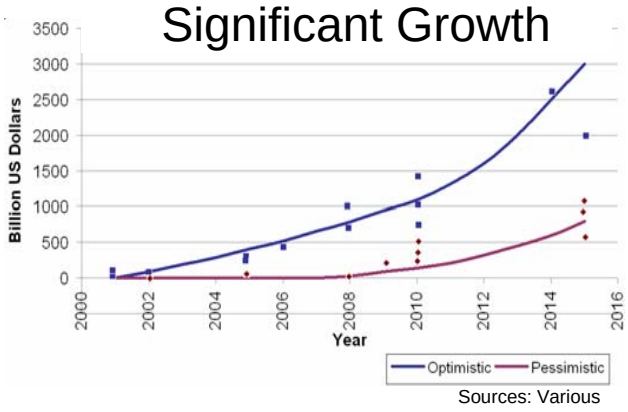
- **Application Areas**
  - Concrete
  - Steel
  - Wood
  - Asphalt
  - Glass
  - Coatings
  - Composites
  - Fire Protection and Safety
  - Water
  - Energy
  - Nano-Computing, Electronics, and Semi-Conductor
  - Metrology



Source: Freedonia 2007

Why Nanotechnology?

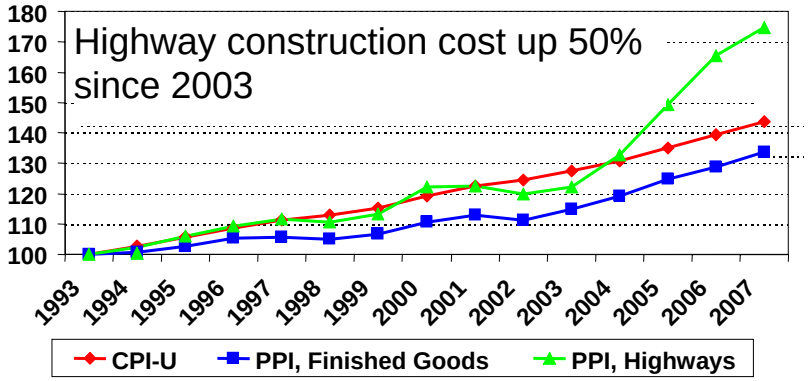




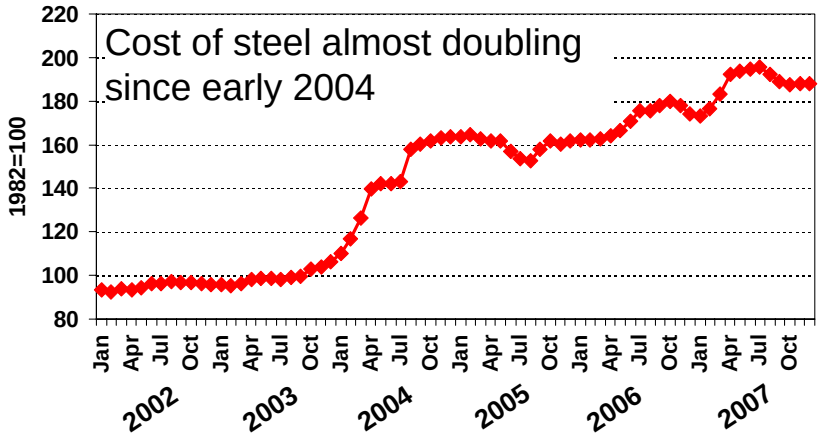
Sources: Various

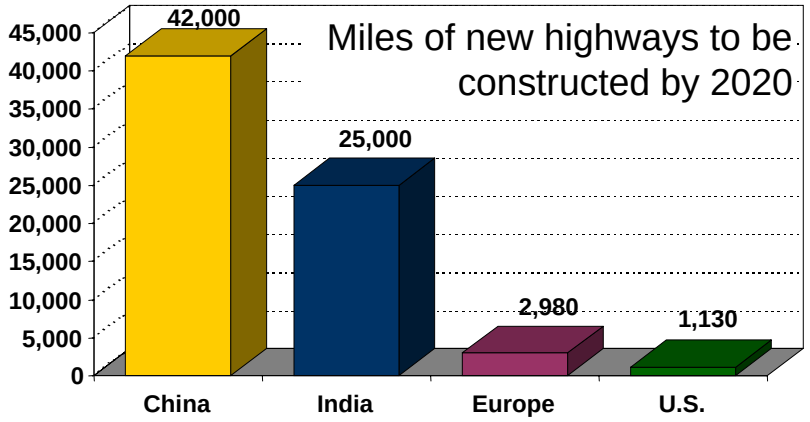
- Current State
  - R&D surging: Global Nano R&D ~$6-9 Billion
  - Nano patents in the U.S. to date: 4,000 (nearly 50% of the world)
  - Over $50 Billion in Nano-products sold in 2006
- Near Future
  - Estimated Market: $2.6 Trillion by 2014
  - By 2015 15% of global manufacturing will use Nano

Why Nanotechnology in Construction?



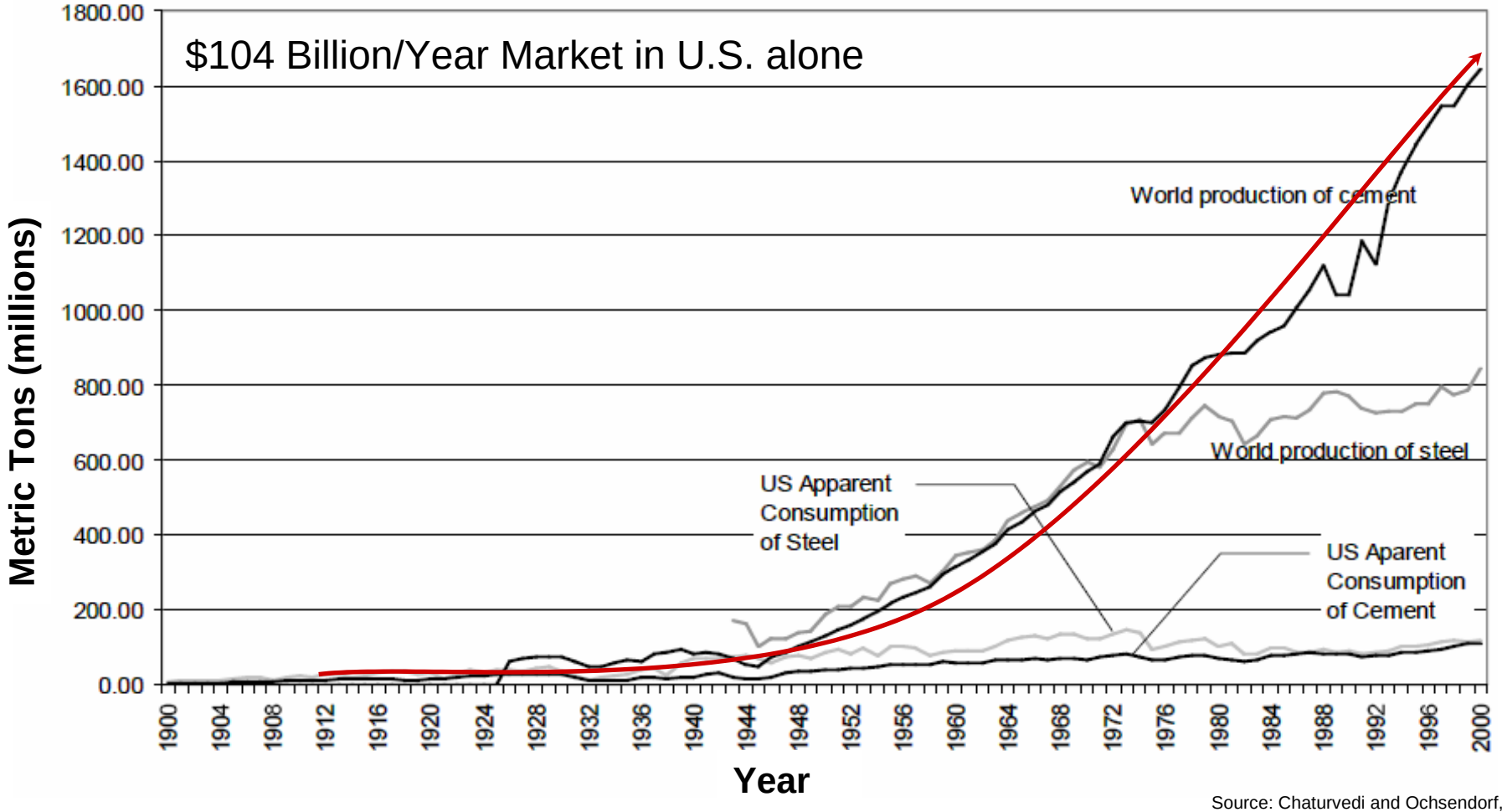
- Skyrocketing construction cost after a decade of modest inflation
- Increasing worldwide demand for larger quantities





Sources: U.S. Bureau of Labor Statistics, The World Bank, India's Ministry of Finance, The European Commission, and ARTBA calculations

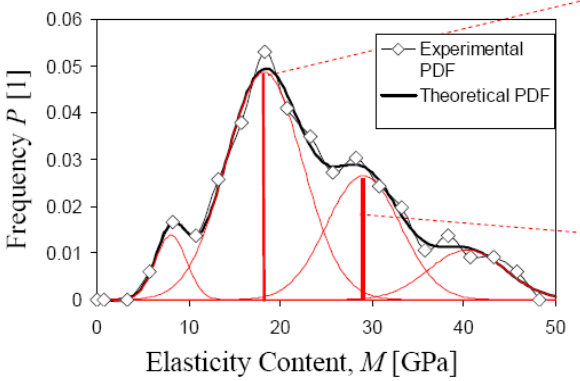
Challenge of Consumption
Example: Cement and Concrete



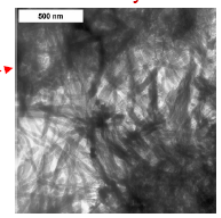
Source: Chaturvedi and Ochsendorf, 2004

Characterization of Materials
Example: Cement and Concrete

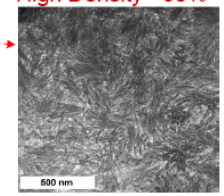
Ordinary Cement Paste: w/c = 0.5



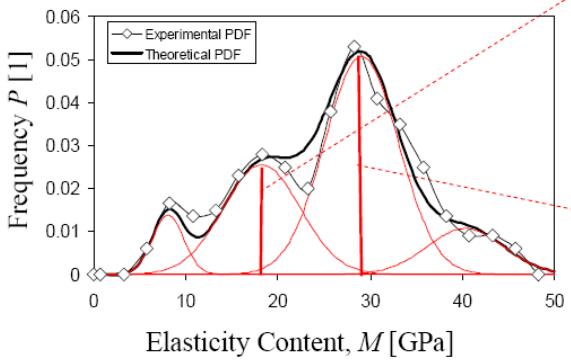
Low Density ~70%



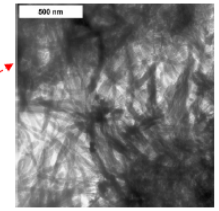
High Density ~30%



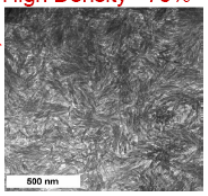
High performance concrete (w/c = 0.4)



Low Density ~30%



High Density ~70%

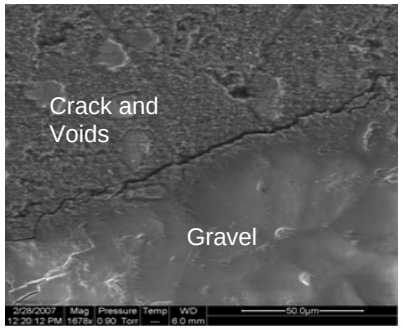


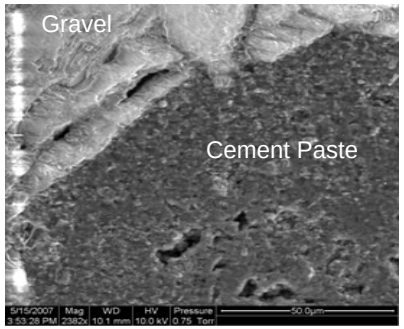
1900–1985 Industrialization/Standardization

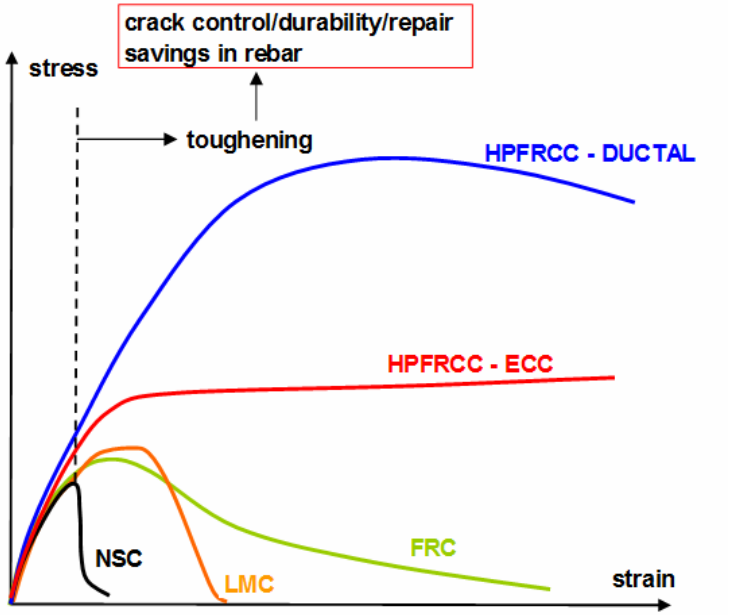
1985-95 Re-discover Diversity

Source: Constantinides and Ulm, 2004

Improved Performance
Example: Cement and Concrete







- Opportunities for Nano-concrete
  - Material (55% of Initial Cost)
  - Labor (45% of Initial Cost)
    - Decrease schedules by 20%
  - Properties
    - Tougher
    - Density (Weight!)
    - Low ductility, weak in tension
    - Durability (Cracking!)
  - Environmental load
    - CO_2 <10%
    - Smog eating, reduce pollution by 40%

Source: Lafarge 2008

Needs Analysis Summary

Definition/Value
- **Use less**
- **Higher functionality**
- **Last longer**
- **Lower maintenance**
- **Less 'Loss of Use'**
- etc.

Characteristics
- **Higher strengths**
- Improved ductility
- **Greater durability**
- Improved recyclability
- etc.

Properties
- Compressive strength
- Flexural strength
- Shear strength
- Ductility/toughness
- Impermeability
- Abrasion
- E-Modulus
- etc.

Impact
- **Quality**
- **Cost**
- **Schedule**
- **Safety**
- **Reduced environmental impact**
- etc.

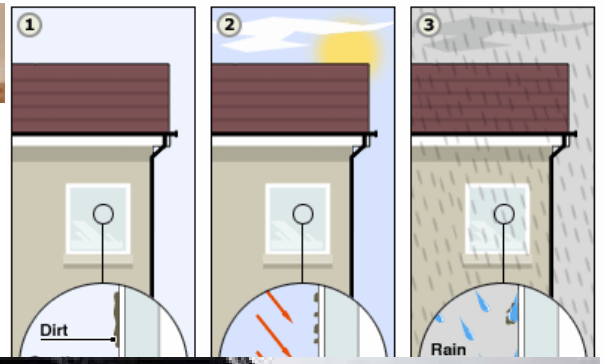
Construction Industry Potential

Nano-House

LifeStraw

- **About 600 products total (after Wilson Foundation)**
- **New paradigm of living**
  - Affordable
  - Self-sufficient energy: heat exchange, lighting, solar/heat energy
  - Quality of life, e.g. aesthetics
  - Life cycle and maintenance and environment
  - Sensors and connecting to electronics
  - Coatings for windows, roofs, and facades
  - Glass – increase R-value
  - Control of pathogens in homes
  - Termite resistant composite wood
  - Increasing structure integrity
  - Increasing adhesives properties
- **Water filtration**
  - Reduces bacteria by 99.9999%, viruses by 99.99%, and parasites by 99%
  - Cost ~$2 and good for 1 year or 700 liters

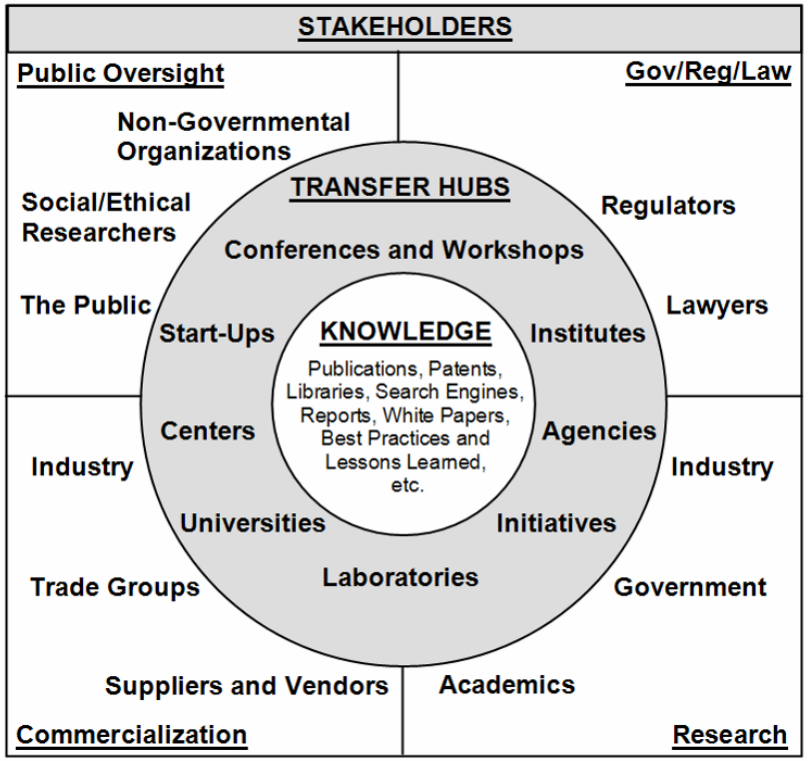
Present	TIMESCALE (years) 0	5	10	20	25+	Destination
Steel	corrosion resistant construction steel					Advanced Bulk Materials: Negligible / zero / positive environmental impact, sustainable resources, pre-set grading of properties replaced by properties optimized for applications properties



ROADMAP: Chart 1 - Bulk Construction Materials

Peter JM Bartos, 2006

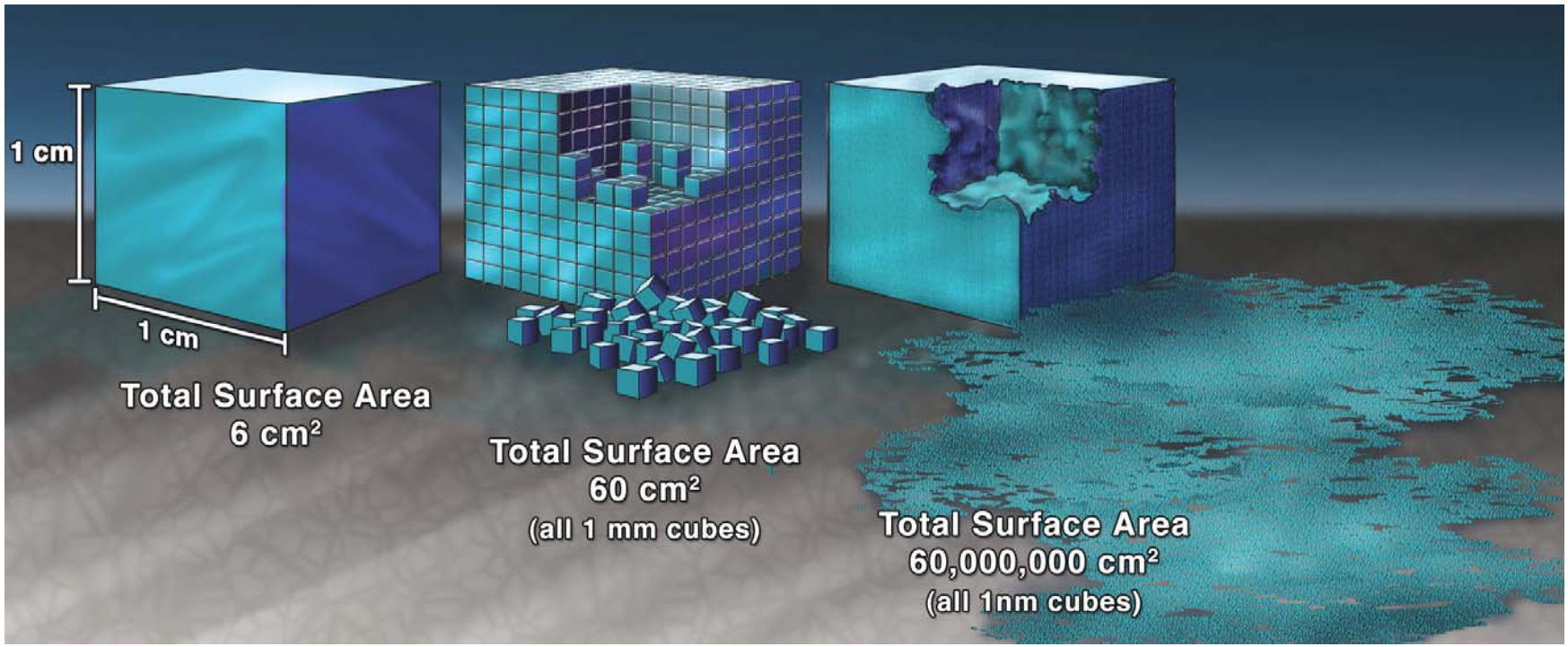
Drivers in the Construction Industry



- Drivers of progress:
  - Competitiveness
  - Investment return
  - Social responsibilities
  - Environmental concerns
- Nanotechnology will set new standards for the construction industry
- “Visionaries”
- Impact on “Bottom-Line”
- Capital for Research and Development
- Understanding of Nanotechnology
  - Missing link between construction industry and Nanotechnology R&D
- Top Down Buy-Ins

Benefits and Barriers

There is a fine line between the good and the bad



Source: Bell, 2006

Benefits and Barriers Summary

- **Benefits**
  - Materials & Properties
    - Strength and Durability
    - Wear and Tear Resistance
    - Corrosion Resistance
    - Fire Resistance and Retardants
    - Aesthetics
  - Economical
    - Life-Cycle and Maintenance Cost
    - Labor
    - Pricing and Profit
    - Customer Satisfaction
    - Market Value and Brand Image
  - Sustainability
    - Energy Efficiency
    - Material Consumption
    - Social and Ethical Benefits
    - Reduced levels of several environmental pollutants
    - Potential for numerous LEED point credits

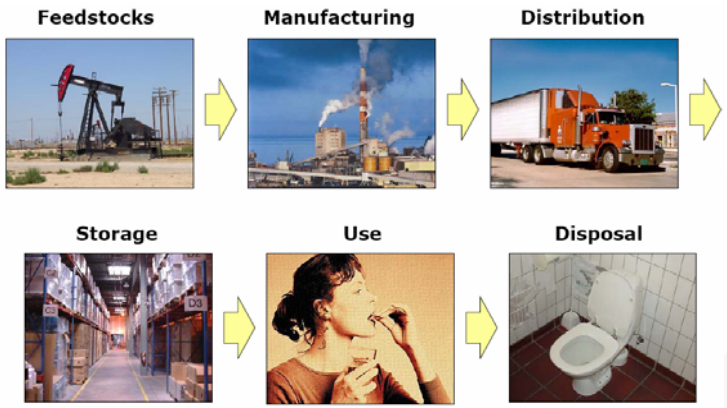
- **Barriers**
  - Safety Concerns
  - Security Concerns
  - Regulatory Agencies – EPA, FDA, OSHA
  - Lobbyist(s)
  - Corporations' established positions
  - Corporations' investment in current equipment
  - Lack of properly trained personnel and cost of training
  - Lack of Understanding (F.E.A.R – False Expectations Appearing Real)
  - Lack of capital by Nanotechnology companies
  - Cost of Commercialization
  - Process must be "Green"

Examples of Nanomaterials, Projected Market Share, and Applications in Construction

- Bulk quantities
- Cost of manufacturing

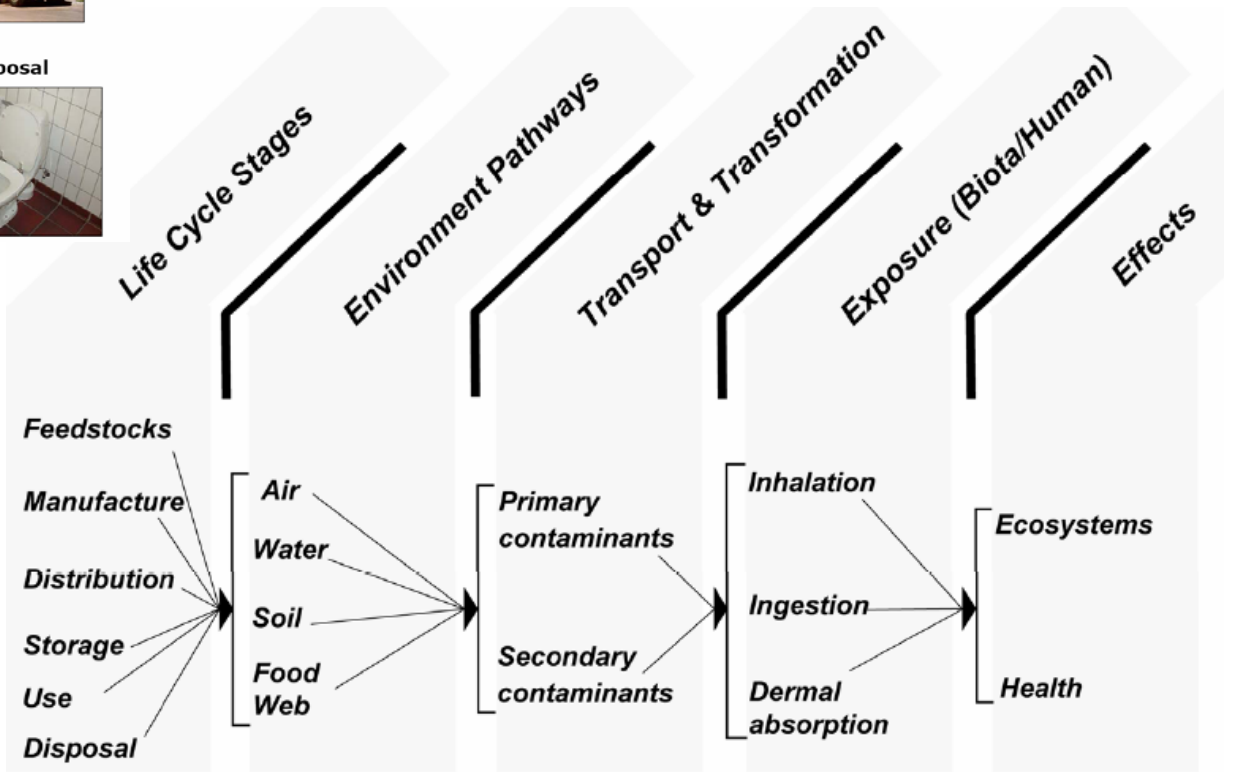
Product Category of Nanomaterial	Market 2005 [$ million]	Market 2010 [$ million]	Material Costs [$ per kilogram]	Primary Applications with Potential in Construction
Ceramic	179	1,500	1-1000	UV absorber, plastics, coatings, photocatalytic coatings, glasses
Metal	89	770	10-10000	Antimicrobial effect
Nanoporous	54	690	10-10000	Insulation, optics, polymers, silicon, oil pipelines
Carbon Nanotubes	43	260	10-10000	Structural composites, memory, sensors, thermal management, display layers, coatings
Nanotstructured Metal	28	198	100-10000	Hard coatings or structural components in aerospace, equipment, pipelines, anti-corrosive coatings
Dendrimers	12	42	100-10000	Coatings, composites, inks, adhesives
Quantum dots	4.3	38	~1000	Optoelectronic applications like LEDs, displays, solar cells, inks and paints
Fullerenes	2.5	60	~1000	Composites, antioxidant additives fuel cells, lubricant
Nanowires	<1	16	~1000	Electronics, for example, Conductive layers for displays, solar cells, logic devices

Why Risk Assessment?



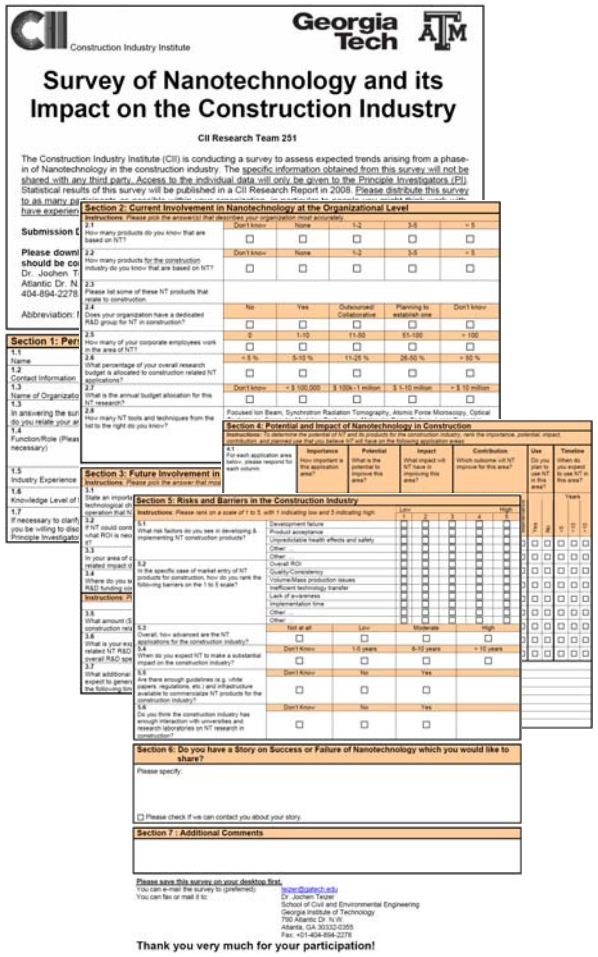
Example:

Risk of Nanotechnology to the Environment



Davis et al., and EPA 2008

CII Member Company Survey


Construction Industry Institute

Georgia Tech

Survey of Nanotechnology and its Impact on the Construction Industry

CII Research Team 251

The Construction Industry Institute (CII) is conducting a survey to assess expected trends arising from a phase-in of Nanotechnology in the construction industry. The specific information obtained from this survey will not be shared with any third party. Access to the individual data will only be given to the Principle Investigators (PI). Statistical results of this survey will be published in a CII Research Report in 2008. Please distribute this survey to as many participants as possible who have experience in construction or production of nanotechnology products.

Section 1: Personal Information

Section 2: Current Involvement in Nanotechnology at the Organizational Level

Section 3: Future Involvement in

Section 4: Potential and Impact of Nanotechnology in Construction

Section 5: Risks and Barriers in the Construction Industry

Section 6: Do you have a Story on Success or Failure of Nanotechnology which you would like to share?

Please specify:

Please check if we can contact you about your story.

Section 7 : Additional Comments

Please save this survey on your desktop first.

You can e-mail the survey to (preferred):

You can fax or mail it to:

Dr. Jochen Teizer
School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Dr. N.W.
Atlanta, GA 30332-0355
Fax. +01-404-894-2278

Thank you very much for your participation!

Objectives:

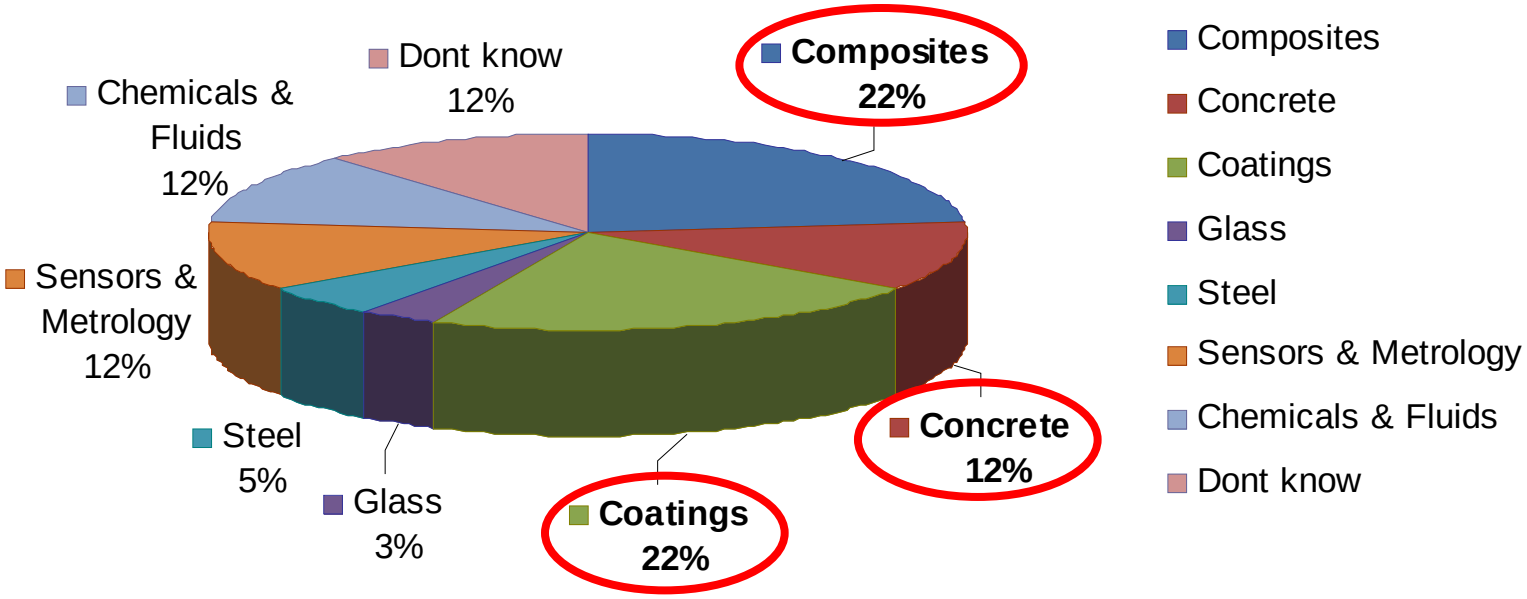
- Experience level
- Current and projected involvement
- Expected potential and impact
- Benefits, risks, and barriers
- Nanotechnology success stories and other comments.

Survey Results (1)

- **149 data liaisons** contacted to identify key personnel within organization
- 34 returned, **6 responses** stated to have no expertise in Nanotechnology
- More than 60% of the participants had **10 plus years** of industry experience
- **8%** called themselves “experts” in Nanotechnology
- 15% knew more than 5 Nano products
- **4%** knew more than 5 Nano products that relate to construction
- **12%** have a dedicated or outsourced Nano R&D program
- **12%** allocate more than 5% of their R&D budget towards Nanotechnology (8% invest more than $1 Million per year)
- **70%** could not identify any of the listed fabrication tools and techniques
- **15%** knew a problem that Nanotechnology could solve in construction
- **30%** require a ROI of more than 15% before investing in Nanotechnology
- **65%** believe Nanotechnology will have little or no impact on construction
- Questions to funding & products under development were not well answered
- The vast majority has **little interaction** with universities and R&D agencies
- The majority does not know whether enough **standards and regulations** exist

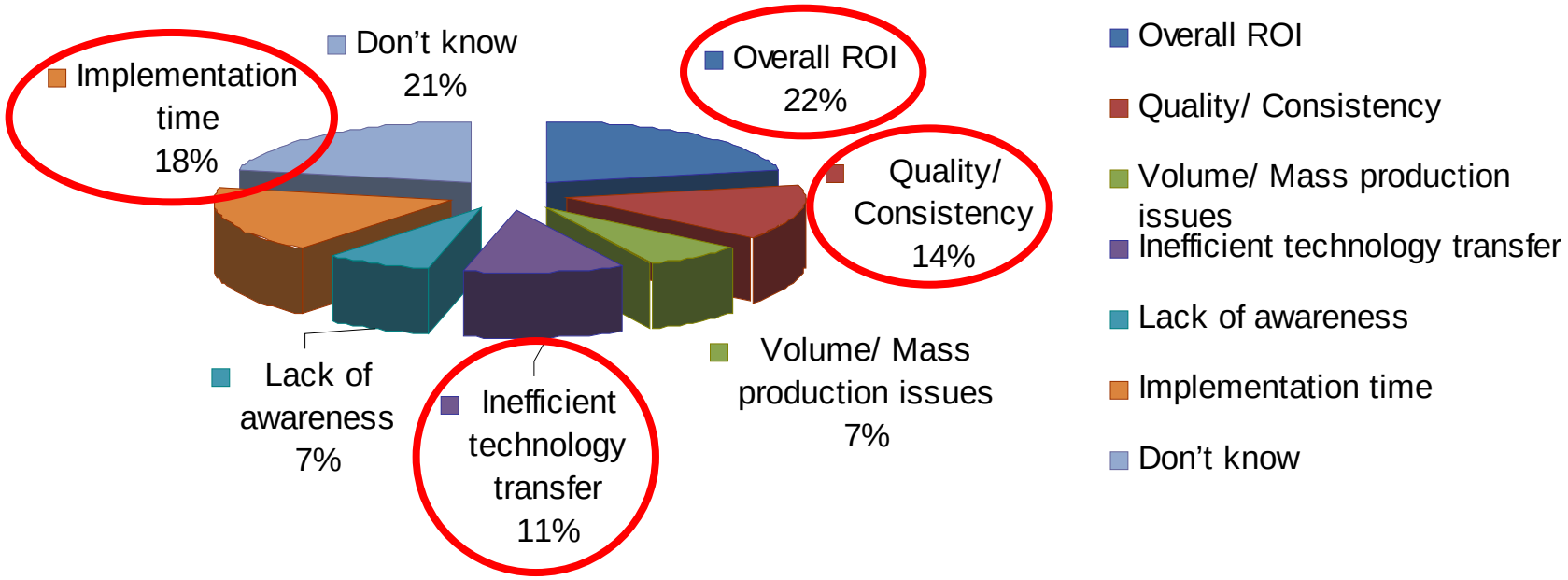
Survey Results (2)

Areas with the biggest impact of Nanotechnology in construction



Survey Results (3)

Biggest risks and barriers to Nanotechnology in construction



5. Examples of Use, Benefits, Limitations for Top 5 Nano-Products in Construction

Product categories	Score	Main Uses	Key Benefits	Key Limitations
Composites	8.46	Building materials (Polymer, Steel, Piping), Energy applications. Protective clothing.	High strength, lightweight, durable structures, ductility, wear and corrosion resistance, earthquake resistance.	Technical limitations and bulk volumes, environmental impact during disposal phase.
Coatings	8.31	Functional surfaces, exterior and interior building surfaces, Industrial piping, Glass.	UV protection, antimicrobial, Scratch, corrosion resistance, water proofing, durability. self-cleaning, longer life, aesthetics.	Cost to produce, not available in bulk.
Concrete	7.53	Bulk material in building construction and capital structures (nuclear, power plants, dams).	Strength and durability, long lasting, aesthetics, schedule.	Manufacturing cost at the level of mass production, higher initial investment, lobbying, environmental at end of life-cycle…
Energy	6.57	Energy storage, production, transmission, extraction, catalysts, devices for solar and wind energy	Cost and efficiency of exploration, for example, oil, longer life of batteries, less losses	Technical limitations, Manufacturing cost at the level of mass production
Sensors & Metrology	6.17	Remote sensing, non destructive evaluation technique (NDE), for example, cracks, fire protection sensors	Low maintenance, minimum infrastructure requirements, Precise and accurate measurement techniques	Product acceptance, Standards and Guidelines

Conclusions and Recommendations

- Nanotechnology can have a **positive impact on our daily life and on the construction industry** and provide better facilities that are essential for businesses and civilizations
- To sustain or profit, the construction industry has to **expect changes which will originate from Nanotechnology (short, medium, long term)**
- Overall* only a few companies seem to have **Nanotechnology expertise or dedicated R&D programs** in place to face the changes Nanotechnology will bring
- A **disconnect** exists between the construction industry and Nanotechnology R&D (other industries as well)
- **Recommendations:**
  - Collaboration and other engagement
  - Maintain a world-class research and development program
  - Facilitate technology transfer
  - Develop educational resources, a skilled workforce, and the supporting research infrastructure and tools
  - Support responsible development of nanotechnology

* Assumption: CII Member Companies are leaders of new technology in the construction industry

Thank you for your attention!

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